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Impact of Agro chemicals on Agriculture and Environment : A Review

Dr. Dhirendra Singh

Principal, Govt. Girls Post Graduate College, Sawai Madhopur, Rajasthan, India.

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ABSTRACT

An agrochemical or agrichemical, a contraction of agricultural chemical, is a chemical product used in industrial agriculture. Agrichemical refers to biocides (pesticides including insecticides, herbicides, fungicides and nematicides) and synthetic fertilizers. It may also include hormones and other chemical growth agents.[1][2] Agrochemicals are counted among speciality chemicals.

Keywords: agrochemicals, agriculture, environment, speciality, chemicals

1. INTRODUCTION

Agrochemicals seep into the surrounding land and water bodies, entering the food chain which leads to bioaccumulation. Regarding their impact on crops, excessive use of such chemicals generates a significant amount of residues. These residues cause nutrient imbalance and quality-reduction of agricultural produce. Global consumption of agrochemicals continues to rise, despite growing evidence of their adverse effects on environmental quality and human health. The extent of increase varies across nations, by type of chemical compounds and by severity of the detrimental impacts. The differential impacts are largely attributable to the level of technology adoption and regulation as well as their enforcement and compliance. The article highlights gaps in technical, legal, and social aspects, which include the paucity of holistic and long-term ecological impact assessment frameworks and lack of consideration for the social dimensions of pesticide use in regulatory decisions. Bridging these gaps, establishing global cooperation for regulation and governance, and a regional/national-level monitoring mechanism are suggested. This, complemented with a policy shift from the current approach of productivity enhancement to augmenting agroecosystem services, would encourage sustainable and nature-positive agriculture equipped to meet the multiple challenges of food security, ecological safety, and climate resilience.[1,2,3]

The market for agrochemicals—inputs integral to modern agriculture—was estimated to be worth 234.2 billion US dollars (USD) in 2019 and is expected to be more than 300 billion USD by 2025 (1). Advocates of agrochemicals vouch for their potential benefits in improving economic efficiency of agricultural production systems and addressing food security concerns. They are seen as responsible for the large increase in food production that has been witnessed, especially since the 1930s, which saw the beginning of the Green Revolution. Modern agriculture has since come to be associated with the use of chemical fertilizers and pesticides. The trigger may be traced to the discovery of the organochlorine compound dichlorodiphenyltrichloroethane (DDT) in 1939. An insect killer that was widely used in the Second World War by soldiers to fight mosquitoes and fleas, it subsequently came to be widely adopted in agriculture and triggered the development of several chemical formulations to ward off pests. The first herbicide or weed killer—2,4-D—was discovered in 1945 and is the forerunner of atrazine, which came in the 1970s, and glyphosate, which came in the 1980s. In 1947, the US government enacted the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Approximately 10,000 new pesticides were reportedly registered in the following five years.

Application of fertilizers, especially nitrogen and phosphorus, provides nutrients required for enhancing the growth of crops. Similarly, pesticides reduce the risk of loss from plant diseases, insect pests, and weeds on agricultural production. Globally, a little more than one-third (35%) of potential crop yield is reportedly lost to preharvest pest attack (2), making a case for the use of pesticides to ensure food production and food security. It is reported that without pesticide use, 78% of fruit production, 54% of vegetable production, and 32% of cereal production would be lost to pest and disease attack (3). In India, for instance, it was the Green Revolution in the 1960s that warded off doomsday predictions of food shortage and famine. The quantum, intensity, and diversity of agrochemicals used globally has enormously increased since the Green Revolution.

At the same time, there is a large and growing volume of literature on the potential environmental and toxicological risk associated with unscientific use of agrochemicals (4). Questions arise as to the economic rationality of pesticide use when the economic costs of damages on ecosystems and human health are considered in the analysis of profitability and efficiency (5). The 1960s saw increasing attention to the environmental impact of widespread use of chemicals in agriculture. DDT is credited with drawing global attention to the environmental impacts of indiscriminate agrochemical use. Environmental historians date the beginning of the second wave of global environmentalism to 1962, following Rachel Carson's seminal work Silent Spring (6). The 1960s also saw a toxic waste spill leading to an outbreak of poisoning on livestock in the United Kingdom, marking what has come to be referred to as the Smarden incident (7). Carson's work saw a surge of public engagement in the hitherto scientific discourses on conservation and environmentalism. This triggered the launch of public-led environmental movements, resulting in the creation of the US Environmental Protection Agency (EPA). The use of DDT for agricultural purposes was banned in the United States in 1972 and the United Kingdom in 1986; however, its use has continued in many developing countries. Since 2001, DDT has been banned for use in agriculture in all the countries that are signatories to the Stockholm Convention on Persistent Organic Pollutants but continues to be used in some developing countries to control vector-borne diseases.[4,5,6]

Notwithstanding these early warnings, the use of chemicals in modern agriculture has continued unabated. The uproar created by Silent Spring was silenced by the modern technological revolution in agriculture, facilitated by policy support and commercial production of inputs that spread across the globe. Many developing countries were able to make commendable strides in grain production in the 1960s and 1970s. This has, however, not been without serious subsequent concerns regarding the ecological and human impacts of agrochemical use (8, 9). For instance, the increase in food production and the associated food-energy-population dynamics has been facilitated by creation of reactive nitrogen (synthetic fertilizers) from unreactive dinitrogen. The reactive nitrogen from synthetic fertilizers, which spreads through the earth systems, has detrimental consequences for human health, biodiversity, and the natural environment (10). This is further corroborated by the extent of biodiversity loss and alteration in surface heat balance resulting in global warming. Both these phenomena are fallouts of land use intensification for industrial agriculture over the centuries (11). A review by Nielsen et al. (12) also points to the direct impact of agricultural intensification and commercialization on soil biomass. The application of nitrogenous fertilizers in industrial agriculture is said to have had a mixed impact on soil microbial biomass. Increases in bacterial biomass activity and activation of the soil nitrogen cycle were observed in response to nitrogen fertilizer application, while simultaneously being detrimental to nematode diversity and activity of mycorrhizal fungi (12).

This article presents a comprehensive review of the recent trends in agrochemical use patterns, farmer-level behavior, and the detrimental impact of these chemicals on ecosystems and human beings, primarily focusing on evidence from published field-level studies. On that basis, a few suggestions are made: (a) promoting sustainable production systems, (b) strengthening global cooperation in research and development; (c) assessing, monitoring, and regulating the use and management of agrochemicals; and (d) adopting eco-friendly green technologies.

The major groups of chemicals in the farming sector are fertilizers, plant growth stimulants, and plant protection chemicals. The technology advancements in the fertilizer manufacturing sector have improved fertilizer formulations from the conventional ones to nanofertilizers. This has also diversified fertilizer materials from macronutrients to micronutrients and soil ameliorants. The application technology of agrochemicals also has undergone changes, from manual methods to use of drones.

Chemical pesticides are broadly categorized as insecticides, fungicides, bactericides, herbicides, and rodenticides. These belong to major chemical groups such as organophosphates, carbamates, organochlorines, triazines, and dithiocarbamates. The latest additions, claimed to be safer alternatives, are pyrethrins and neonicotinoids. The mode of action and ecological and human health effects of the formulations vary according to the chemical groups. Although herbicides account for the majority of pest control chemicals globally, there are differences in proportion of use of different pesticides across countries. For instance, herbicides are the major group of agrochemicals consumed in the United States, whereas insecticides are the major group in countries like India. This is mainly decided by the cropping pattern, climate, and technology diffusion.

The global consumption of mineral fertilizers in 2019 was 188.54 million tonnes, which was a dramatic increase of more than six times from 30.85 million tonnes in 1961, the pre–Green Revolution period. The global population during the same period increased from 3.1 billion to 7.7 billion. The consumption of nitrogen fertilizers alone saw a massive increase of more than 250% in the five decades between 1969 and 2019 (13)

A study examining the consumption of fertilizers and pesticides found that 88 countries on average consumed 110 million tonnes of NPK fertilizers annually during the 1961–2010 period (14). China was the largest consumer, using 21.6 million tonnes/year, followed by the United States at 17.5 million tonnes/year, and 18 countries each used more than one million tonnes/year. With regard to insecticide consumption, average annual consumption from 1990 to 2010 by 82 countries was 342,000 tonnes, with the United States consuming the largest amount at 90,000 tonnes/year, followed by India at 30,600 tonnes/year and 34 countries using more than 1,000 tonnes/year on average. Average annual herbicide consumption of 75 countries during the same period was 566,000 tonnes, with the United States reporting the highest consumption at 201,000 tonnes/year, followed by Mexico at 34,400 tonnes/year and 45 countries using more than 1,000 tonnes/year. In the case of fungicides and bactericides, 353,000 tonnes were consumed annually across 77 countries, with Italy consuming the most at 61,700 tonnes each year, followed by France at 46,400 tonnes/year. Brazil is the second largest consumer of pesticides, after the United States. China is at par with Brazil and is also a major producer of pesticides. Bangladesh and Thailand quadrupled their pesticide use between the early 1990s and early part of the past decade, while newer entrants, such as Ghana, Ethiopia, and Burkina Faso, saw a tenfold increase over the same period [6,7]. The use of pesticides in Africa, although low, was found to be increasing especially in West Africa, following the onslaught of the fall armyworm (FAW) in 2016. Developing countries accounted for only one-quarter of global pesticide use [7,8]

2. DISCUSSION

Agrochemical pollution is a serious threat to environmental safety. Exposure to agrochemicals had deleterious health effects such as nervous system damage and cancer. Biological magnification of persistent agrochemicals also occurred. Hence, remediation approaches for agrochemical pollution must be a holistic approach, including environment and crop produces. The advent of nanotechnology helped to formulate highly efficient methods for the remediation of agrochemicals. High reactive surface area and very small packing space requirements made usage of nanoparticles as a popular agent in agrochemical remediation. Growing interests in surface-engineered nanoparticles promise complete removal of agrochemicals from the environment. Nanosorbents immobilized agrochemicals in the soil and helped microbial degradation of these compounds. However, many of the agrochemicals are persistent, and hence complete removal of these residues practice via photocatalysis. Photocatalytic degradation of persistent agrochemicals using bimetallic nanocomposites widely adopted. Large-scale environmental remediation of agrochemicals in soil, water, and agriculture products achieved via nanoparticles-based agrochemical cleaning systems such as thin-film fixed-bed reactors and nano-phytoremediation.

Agrochemicals, such as pesticides, are used in the Mekong Delta to protect, manage, and enhance agricultural production. However, once applied, the chemicals are introduced not only to the agricultural area but also the wider environment through natural hydrological processes. Accumulation of agrochemicals in soil and water can have negative impacts on aquaculture, potentially affecting the health and welfare of the farm stock, quality of the produce, and may even result in food safety issues for humans. Consequently, the use of agrochemicals and their fate is of great concern to the aquaculture industry in the Mekong Delta as it may affect sustainable development of the sector. Pham (2012) used GIS and spatial models to investigate agrochemical use, distribution, and accumulation in the lower Mekong Delta in Vietnam.[3,4,5]

The agrochemicals also subsidize a key role in causing air pollution. The agrochemicals sprayed in agricultural fields were suspended in the air and polluted it which was drifted away to the other areas posing a threat to wildlife (Ansari et al., 2014). The traces of DDT, lindane, and aldrin were detected on the equator in India and the high altitude of cold regions even in the Greenland ice sheet due to the circulation of atmospheric and ocean currents and enrichment of biological pesticides (Zhang et al., 2011). According to Vorkamp and Riget (2014), the insecticide, organothiophosphate, was reported in the air and also in the seawater in the Arctic region, which confirmed the long-range passage of these agrochemicals. The endosulfan has also been reported in the animals from Greenland (Vorkamp and Riget, 2014). The weather conditions during the application of agrochemicals also affect the spreading of agrochemicals. Therefore the quantity of inhalable agrochemicals in the environment is dependent on the season (Damalas and Eleftherohorinos, 2011). Other parameters such as solubility of agrochemicals in soil, soil texture, molecular properties, and concentration of agrochemicals also play a significant role in mixing of agrochemical residue in the air. The spraying of agrochemicals at ground level has less chances of drift in the air as compared to aerial application. Farmers must be educated about the harmful effect of these agrochemicals and can also make a buffer zone around their fields, which consist of empty land or noncrop plants such as evergreen trees. These boundaries of trees around the agricultural fields serve as a windbreak and also absorb the agrochemicals that prevent the drift of the same into the other areas.

Agrochemicals are widely used in agriculture to manage pests and phytopathogens. Hence, it is very pertinent to study the fate and behavior of applied agrochemicals in soil. The important factors that affect the persistence of such agrochemicals such as clay type, clay content, SOM, and pH of the system are described in this chapter along with the mechanisms of retention in soil. Long-term persistence of agrochemicals is harmful for succeeding crops grown in the soil as they leave residues that may enter into the animal and human food chain. Many of the agro-pesticides exist in the soil environment as a mixture. Currently our knowledge about the fate and behavior of agro-pesticide mixtures in the ecosystem is inadequate. Therefore, research is needed in the future to address the issue of agro-pesticide mixtures in the soil–plant systems under various agro-climatic conditions.[2,3,4]

3. RESULTS

If used correctly and safely, agrochemicals can prevent and control pests, diseases, and weeds to greatly improve the harvests of coffee farmers. However, during spraying, only a small amount of the toxic chemicals reaches the targeted pests, diseases, and weeds. The rest contaminates the surrounding soil, air, and waterbodies – which brings harm to useful living creatures in ecosystems. In our previous blog articles, we explored how exposure to toxic agrochemicals affects smallholder farmers and their families. But how do agrochemicals affect the environment? And what is the link between agrochemicals and climate change?

1. EFFECTS OF AGROCHEMICALS ON TARGETED ORGANISMS

Although agrochemicals can effectively rid coffee plants of pests, diseases, and weeds, this is not always the case – particularly if the wrong dosage of the chemicals is applied. Pests will naturally begin to adapt to their environment by either migrating to a new area or genetically mutating so that they can survive under the toxic conditions. The mutation of insects can make them resistant to the pesticides and/or enhance their reproductive abilities in a bid to prevent extinction. Overtime, this can lead to a higher population of pests and increased incidents.

2. EFFECTS OF AGROCHEMICALS ON NON-TARGETED ELEMENTS AND ORGANISMS

2.1 Soil

Nitrogen is an important element for soil fertility, and it enables plants to grow. Bacteria are the organisms in soil that create nitrogen and make the soil fertile. However, once agrochemicals spill over from the plants to the soil, they can be detrimental to the population of bacteria. This can subsequently affect the levels of nitrogen and other minerals in the soil – making it less conducive for plant growth.

Like bacteria, earthworms also play a significant role in enhancing the quality and fertility of soil. They decompose organic matter which essentially turns into a natural manure for plants. Worms also play a vital role in the soil's structure by creating channels for plant irrigation, and soil drainage and aeration. However, pesticides cause a decline in earthworms and stunt this natural process. This can lead to increased soil erosion and depletes the soil making it not conducive for plant grow.

2.2. Air

Pesticides have the potential to contaminate our air, affecting the health of humans, animals, and plants. During spraying, strong winds can cause agrochemicals to drift and contaminate nearby surfaces. Aside from this affecting the health of humans in nearby settlements, it can cause a ripple effect that can adversely affect ecosystems. When they drift to nearby plants, insects and waterbodies, agrochemicals can expose important pollinators like bees, fruit flies and some beetles to pesticides either through inhalation or ingestion. Overtime, this can lead to the loss of plant species because of the lack of adequate populations of pollinators.

Livestock, birds, and other animals can encounter the agrochemicals in the air through inhalation, absorbing it through their skin or ingesting them through feeding on contaminated plants or seeds. Although this exposure is rarely fatal for larger animals, high levels of pesticides can be found in the meat of livestock which humans eat. Pesticides can also lead to high mortality of smaller animals like birds. Birds and other predators like spiders play a critical role in ecosystems because they help maintain the natural balance of insect populations by eating them, and some species like hummingbirds are also important pollinators. Therefore, a decline in the population of birds could lead to an increase in plant pests/insects as well as the loss of some plant species.

2.3. Water

Pesticide residues can drift into waterbodies through the air, accidental spillage, rain runoff from contaminated soil or washing the spraying equipment after use. Excessive use of agrochemicals can also lead to the contamination of groundwater with nitrate, a chemical compound that in large concentrations is poisonous to humans and animals. Aside from the contaminated water affecting the health of the animals that come into contact of it – including livestock and humans – pesticides have been directly linked to causing fish mortality. Fish are an important part of marine ecosystems because they provide food for other mammals and birds. Therefore, a decline in the population of fish would greatly affect many other animals in food chains and food webs.

3. LINK BETWEEN AGROCHEMICALS AND CLIMATE CHANGE

The increased use of agrochemicals is a side effect of climate change because higher temperatures trigger increased incidents of pests and diseases. At the same time, producing and using agrochemicals to control the pests and diseases creates climate problems. The production of nitrogen-based fertilizers "is energy-intensive, requiring the burning of fossil fuels. After farmers apply these synthetic fertilizers to crops, chains of chemical reactions generate nitrous oxide, or

N_2O, a greenhouse gas. N_2O has a far greater global warming potential than either methane or carbon dioxide—265 times more by weight as CO_2."

4. SOLUTIONS

Forgoing agrochemicals may seem less efficient and more labor intensive, but it is a much more environmentally friendly alternative to the use of pesticides. And if a farming family manages their farm in an agroecological manner, they attract more predators of coffee pests, more birds, wasps and bees that help protect the coffee plants.

However, c&c does not condemn the use of agrochemicals in coffee production. The fact that smallholder families are able to purchase external inputs is a sign of development. But alternatives do exist, and we need to provide these families with all relevant information and knowledge to be able to apply them. Read our previous blog to learn about how the initiative for coffee&climate (c&c) and implementing partner Hanns R. Neumann Stiftung (HRNS) are doing just this![5,6,7]

4. CONCLUSION

Currently, more than thousands of agrochemicals or pesticides have been applied in agriculture at the different phases of growth at the start of germination to the fruiting stages of crops, vegetables, or fruits. Pesticides applied in agriculture have a different role such as to meet the requirements of nutrients in soils, or to check the growth of phytopathogens, or to control plant diseases. But the continuous application of chemical fertilizers or pesticides in agricultural land severally affect the texture, productivity of both plant and soil, native microflora of the soil, or the surrounding environments. After the application of pesticides on fruits, vegetables, and crops, some extent of these pesticides get deposited on different parts of fruits and crops as chemical resides. The consumption of these pesticide residues shows mutagenic, carcinogenic, cytotoxic, genotoxic, and also a range of health-related issues in human beings.[8]

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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